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[From The American Journal of Science, Vol. XXXII, October, 1911.]

A STUDY OF THE TIME INTERVAL IN A PROTECTIVE OR CIRCUIT BREAKING DEVICE.

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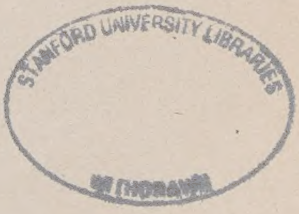
A THESIS

PRESENTED TO THE FACULTY OF THE GRADUATE SCHOOL OF THE UNIVERSITY OF PENNSYLVANIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.



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ART. XXXII.—*A Study of the Time Interval in a Protective or Circuit Breaking Device;** by CALVIN NAFTZINGER WENRICH.

IN the ordinary plunger circuit breaker, the time between the starting of the iron core and the releasing of the spring is very short. This time is not appreciably affected by a change of current after the starting of the core. Such an interval in a breaker is called the "time element."

The fuse, when used as a breaking device, acts on the principle of an "inverse time element," that is, the greater the excess of current above the maximum amount which the fuse will permanently carry, the shorter is the interval before the circuit is broken. This is a desirable feature. The fuse, however, is non-adjustable in its time feature and very dangerous from the standpoint of ignition at its blowing temperature. These features make it undesirable as a circuit breaking device.

If a circuit breaker is to serve as a heat protector, it ought to operate on the principle of an "inverse time element." An automatic device should act quickly on a large overload and very slowly on a small overload, defining "overload" as the excess of current above the value at which the device would not operate during any length of time. From the standpoint of the definitions of "time element," "inverse time element," and "overload," a few of the most popular breakers will be examined.

The mounting of a copper or aluminium disc on a horizontal axis in a rotating field has been resorted to frequently for an inverse time feature. A weight is supported by a fine cord on the pivoted horizontal axis. The driving torque of the rotating field just balances the weight under normal conditions. In the case of an overload, the weight is raised by the driving torque and in its motion engages two contact points in the tripping circuit. The length of the cord finishes an adjustment for the time element, while the resultant driving torque gives the inverse time element. The magnitude of the weight lends the adjustment for the overload.

This method—the winding of a cord on a spindle, where the weight is the resisting force—has been used in a variety of ways.

The "clock type" of relay consists of a clock mechanism which is released by an armature suspended above the poles of a magnet. The magnet is energized by the time current.

* Thesis presented to the Faculty of the Graduate School of the University of Pennsylvania in partial fulfilment of the requirements for the degree of Ph.D.

The circuit of the tripping element is completed when the armature is held down by the magnet and then only after the clock has unwound a predetermined amount. This contact, in the tripping circuit, effected by the unwinding of the clock, is made in many different forms. The magnet may be made to operate for any definite current depending on the distance between the poles and the armature. The time between the release of the clock mechanism and the making of contact in the tripping circuit is not determined or affected by any particular armature setting, but rather by the amount of unwinding. Here, then, we have no inverse time element.

The amount of unwinding for any particular release may be varied and easily adjusted for any specified time to trip. If the relay is set to release the clock mechanism at 200 amperes and the unwinding adjusted to make contact in 2 seconds after the release, the circuit will open in 2 seconds provided the line current remains at 200 or more for 2 seconds.

If, however, the line current falls below 200 before the 2 seconds are up, the armature goes back and hence no contact can be made to open the circuit. This is not a desirable relay. While it has the important feature of operating on both D. C. and A. C., it has no resetting element. After each time the contact is made, the clock must be wound. It gives little assurance of reliability in the clock mechanism stopping to unwind, if, during the predetermined time for tripping, the line current falls below the value necessary to effect a release.

Perhaps the most popular relay with an adjustable inverse time element is the bellows type. Here the actuating mechanism consists of an iron core in a solenoid compressing a bellows in its upward movement. The bellows is attached to the upper end of the iron core. There is an adjustable needle valve in the bellows for controlling the escape of air. A retarding force is furnished by the air pressure in the bellows. The inverse time element is controlled by the adjustable valve. The tripping circuit is completed by a ring on the iron core engaging two contact pieces in its upward motion. The time element adjustment is furnished by the distance between the engaging ring on the iron core and the contact pieces. For overload adjustments suitable weights are placed on the engaging ring. This is both a D. C. and A. C. relay. A variation from this particular form is the substitution of a dashpot for the air bellows. This shows that the ordinary plunger circuit breaker may be modified by attaching to the iron core a bellows or dashpot, thereby getting an inverse time element attachment. The tripping circuit is generally separated and energized by a storage battery. In this investigation, the aim

was not only to study the time functions in circuit breakers now in use, but also to devise additional protective methods.

In the three devices described above the operating principle is that of magnetism.

With the exception of one or two devices where the expansion of metallic rods is used for completing a tripping circuit, no work, having heat for its operating principle, seems to be recorded. Attacking the problem from this point of view, the principle of the Nernst lamp was first used. The amount of current in the glower is some function of its temperature. If then the line current through the heater heats the glower, and at a certain temperature the glower allows enough current to pass through its shunt from the line to energize a tripping magnet, the system furnishes a good inverse time element. For the higher the current in the heater, the shorter will be the time necessary to heat the glower to the required temperature.

An old style of Nernst heater was obtained and the glower placed on the inside. Even with the glower in this position it took from $1\frac{1}{2}$ to 2 minutes for $\frac{1}{2}$ of an ampere to heat the glower to the temperature required for operating the tripping magnet. The glower and the magnet in series were placed in shunt with the heater. The time for heating the glower to the operating point was too long, and the current used too high, to give satisfaction.

After an extensive search it was found that fused lead chromate has properties similar to those of the Nernst glower. In the same position as the glower, it took less time and current to operate the tripping magnet. The behavior of the chromate seemed very promising and hence it was thought profitable to plot a curve connecting its resistance with temperature.

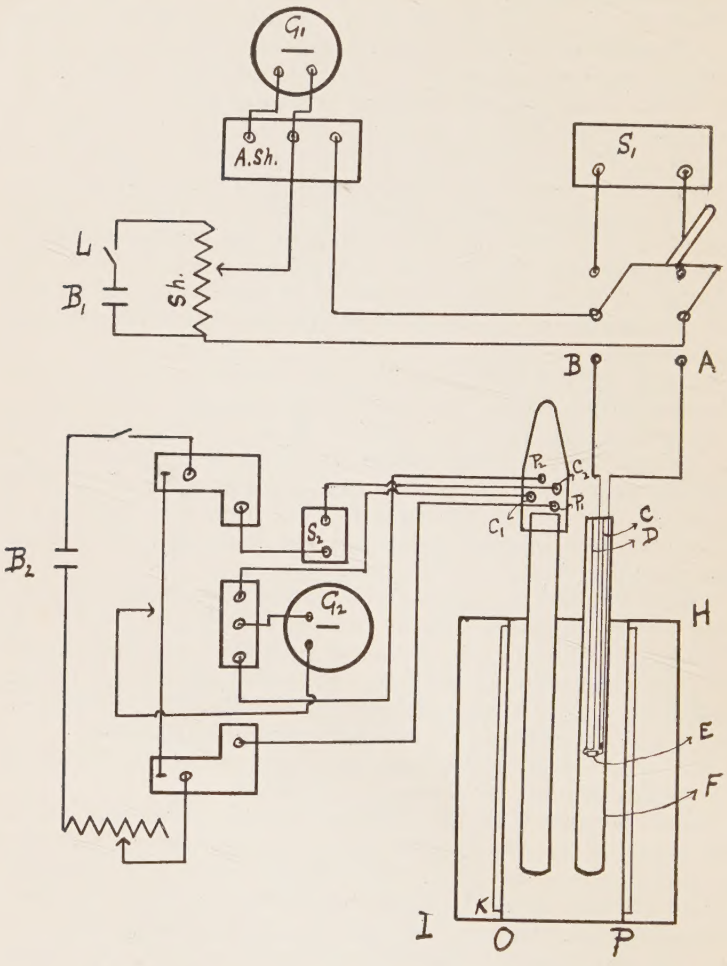
The accompanying diagram (fig. 1) shows the connections of the apparatus used for obtaining the data.

HI is the electric furnace in which the chromate was heated. The temperature was determined by a compensating lead type of platinum thermometer. The thermometer was connected to the ordinary form of a slide wire resistance bridge as shown in the diagram. G_2 is a Leeds and Northrup testing galvanometer; S_2 is a variable standard resistance chosen very nearly equal to the platinum, so that the balance was obtained near the center of the bridge. P_1 P_2 C_1 C_2 are the terminals of the thermometer. The leads from these terminals to the bridge were specially constructed for this purpose, with the aim of making the bridge very symmetrical and more accurate.

The platinum of the thermometer was incased in a porcelain tube, and to have as nearly as possible a correct temperature of the chromate, this was mounted in a similar way. A porcelain tube F of about the same size as that of the thermome-

ter was used. Into this tube a pipe-stem CD was projected to the distance shown in the diagram.

Fig. 1.



Two platinum wires were fused into a small cylindrical piece of well-fused lead chromate E. The piece was 0·5^{cm} long and 0·15^{cm} in diameter. This was suspended from the end of the pipe-stem with one wire coming through the stem to B and fastened with furnace cement to the lower end of the stem. The other wire was conducted out between the stem and the tube to A. The latter wire was fastened to the outside of the

lower end of the stem with cement. This gave a firm suspension and prevented short-circuiting. The top of the tube was closed with cement, care being taken not to make it air-tight. The platinum wires were soldered to heavy brass bars just outside the tube.

A furnace was built especially for the purpose of heating the chromate. The construction is very similar to that described in the Bulletin of the Bureau of Standards (vol. vi, No. 2, p. 160, 1909). In building the furnace "Nichrome" ribbon was used instead of platinum. The method of measuring the resistance of the chromate was that of comparison.

In the figure, G_1 is a Leeds & Northrup type K galvanometer which was used with a telescope and scale at a meter's distance. The sensibility of this instrument is 446 megohms with a resistance of 120 ohms. An Ayrton shunt was used in connection with it, as seen in the figure. S_1 is the variable standard with which the resistance of the chromate was compared.

The constants of the thermometer were determined and are recorded with Table I. The ordinary formula for calculating the temperature from the change of resistance and temperature coefficient was used.

It was noted that when the chromate was heated to a high temperature, it had a higher resistance after cooling than it had before heating it. On a second heating to a temperature considerably lower than the first, it showed little or no variation after cooling. At room temperature it was very stable.

The curve given in fig. 2 was obtained from a piece that had been heated twice for several hours with the range of temperature used for the curve. Through this range the chromate has a very large negative temperature coefficient. The points on the curve are somewhat irregular. It was impossible to determine the causes of all the variations which were observed for the whole range of temperature.

When the switch was on A and B with L open and the chromate at a temperature of about 350° centigrade, the galvanometer mirror swung to the extreme right of its zero position; at about 400° to the extreme left; at 475° to the extreme right again, and so on until at 800° there had taken place six distinct reversals. Some of these movements, especially at high temperatures, were quite violent and off the scale. On cooling, the reversals were repeated in reverse order at about the same temperatures.

The curve given in figure 2 was obtained by impressing an extra E.M.F. on the shunt marked *sh* in figure I. With this E.M.F. balanced with the unknown E.M.F. in the circuit, a zero position of the galvanometer was obtained. L was now closed and a reading taken.

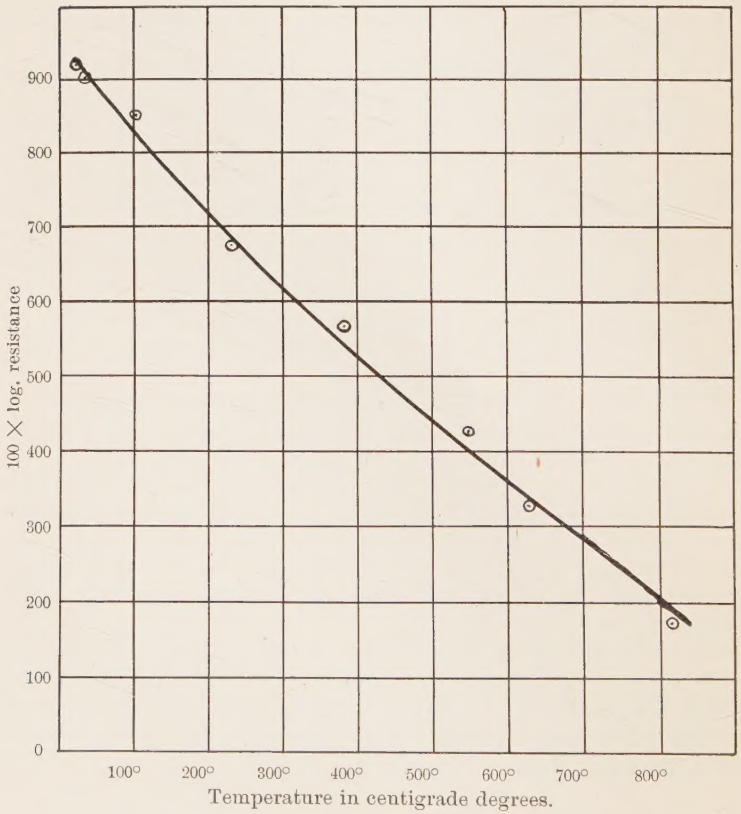
TABLE I (FOR FIG. 2).

Readings	Av. defl. in cm. for the chromate	Av. defl. in cm. for S_1	S_1	Calculated resistance of the chromate	Average reading on the bridge	S_2	Cal. resistance of ther.	Cal. temperature
1	0·23	81·0	$4·917(10)^6$	$1·7\bar{3}\ (10)^9$	48·99	3	$2·88\bar{0}$	22·69
2	0·33	80·95	$4·917(10)^6$	$1·20\bar{6}(10)^9$	$50·06\bar{5}$	3	$3·00\bar{7}$	34·80
3	1·07	80·4	$4·917(10)^6$	$3·69\bar{4}(10)^8$	48·34	4	$3·74\bar{6}$	105·4
4	6·69	8·08	$4·917(10)^6$	$5·93\bar{0}(10)^6$	50·46	5	$5·09\bar{2}$	233·6
5	8·73	10·91	$3·99\ (10)^5$	$4·98\bar{6}(10)^5$	47·64	7	$6·36\bar{9}$	355·3
6	12·43	$11·71\bar{5}$	$2(10)^4$	$1·88\bar{4}(10)^4$	51·22	8	$8·40\bar{9}$	550·3
7	1·25	2·37	10^3	$1·90\bar{0}(10)^3$	50·67	9	$9·24\bar{4}$	629·4
8	12·57	6·785	10^2	$5·39\bar{7}(10)$	50·525	11	$11·2\bar{3}$	819·0

Constants of the Platinum Thermometer.

$R_0 = 2·64\bar{2}$ ..... Temperature of steam was 100·32°
$R_s = 3·692$ ..... Average barometer was 30·37 inches
$R_{100} = 3·688$ ..... Fundamental interval = $1·04\bar{6}$
Temperature coefficient = ·00397

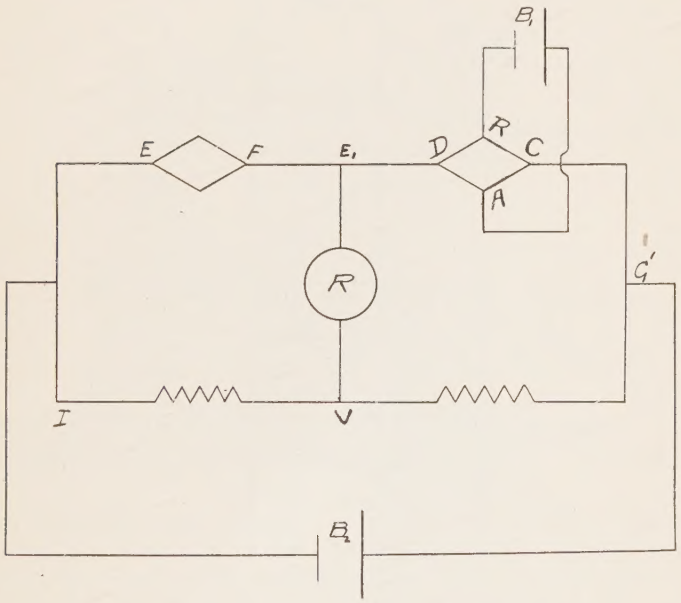
FIG. 2.



A piece of chromate similar to the one under test was prepared, and a current with considerable density was passed through it for about 18 hours. No trace of transformation or decomposition could be found. Time did not permit any further investigation of the causes for the unstable condition of the chromate at these temperatures, and since this behavior did not warrant its use for a protective device, the principle of the Nernst lamp was abandoned for the time being. The chromate will be examined again in the near future with the hope of obtaining more definite data.

The original problem was now attacked on the principle of the bolometer. Figure 3 shows the general plan of the appa-

FIG. 3.



ratus. B_2 is the battery furnishing the bridge current. IV and VG′ are two resistances of about 10 ohms each adjusted very nearly equal. The eight arms in the bridges EF and DC were adjusted electrically equal as nearly as possible. Each arm consisted of about 10 ohms resistance. The bridge, then, as a whole, balanced for a wide range of current, and remained so for any variation of room temperature. B_1 is the source used to heat the small bridge DC, thereby unbalancing the large bridge, and consequently having a current through R. R is a relay which contains in its circuit a tripping magnet. If then the source B_1 were shunted off the line, and the line

connected with the tripping magnet, we would have a device for breaking a circuit for an overload in a time which was some inverse function of the current in the line.

On account of its high temperature coefficient, iron wire was chosen for EF and DC. The wire used was 0·01^{cm} in diameter. "Advance" wire was chosen for IV and VG′ on account of its practically zero temperature coefficient. EF and DC were

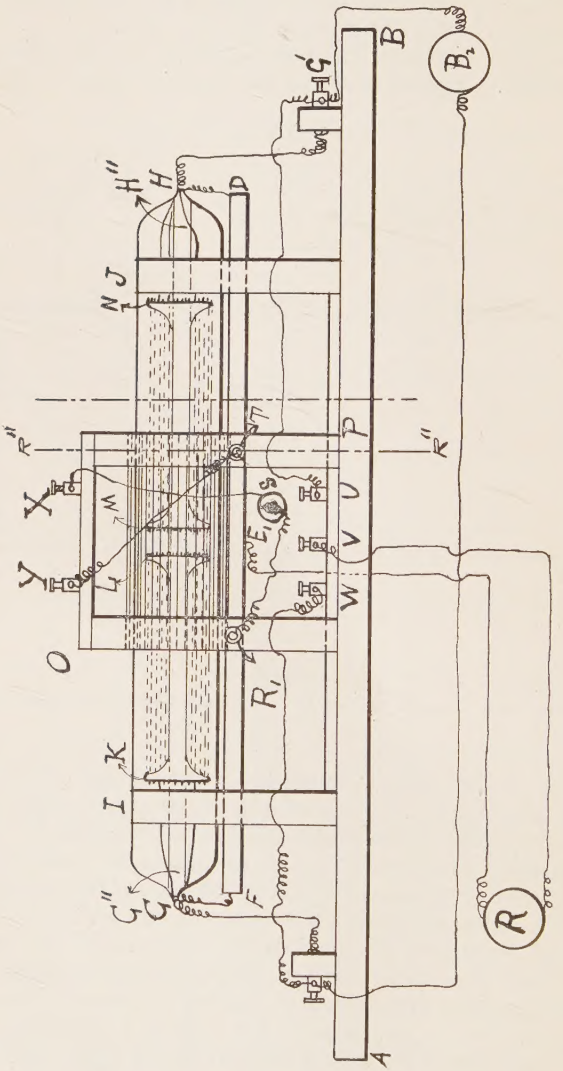
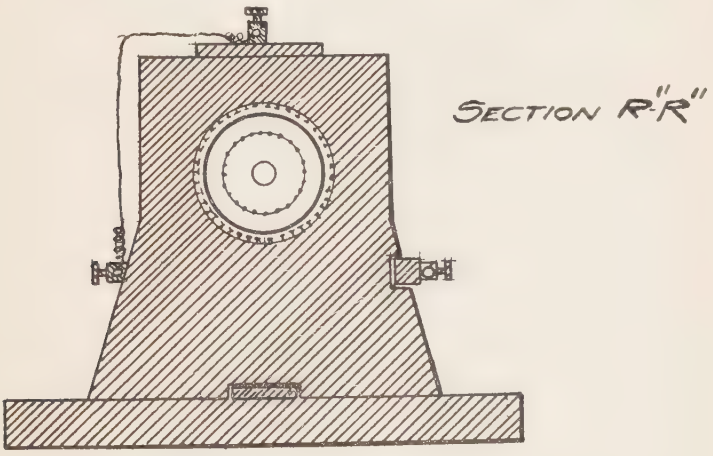


FIG. 4.

mounted as shown in figure 4. See also fig. 6 for an end view. Corresponding letters are used in figures 3, 4, and 6. K, L, M, and N, fig. 4, are 4 glass discs blown on the small tube G"H" which is contained in the larger exhausted tube GH. The discs are 3·8^{cms} in diameter. The distance from K to L is 17·8^{cms}; from L to M 1·27^{cms}; and from M to N 17·8^{cms}. The whole length of the tube is 50·8^{cms}. The four arms in DC, figure 3, are strung on the discs M and N, figure 4, as shown by the dotted lines. Each arm taking up six lengths, has its terminals at N. An end view of the disc with the binding posts for these terminals is shown in figure 6. The brass binding posts E, R, etc. are fastened to a plate of mica which is cemented to the disc.

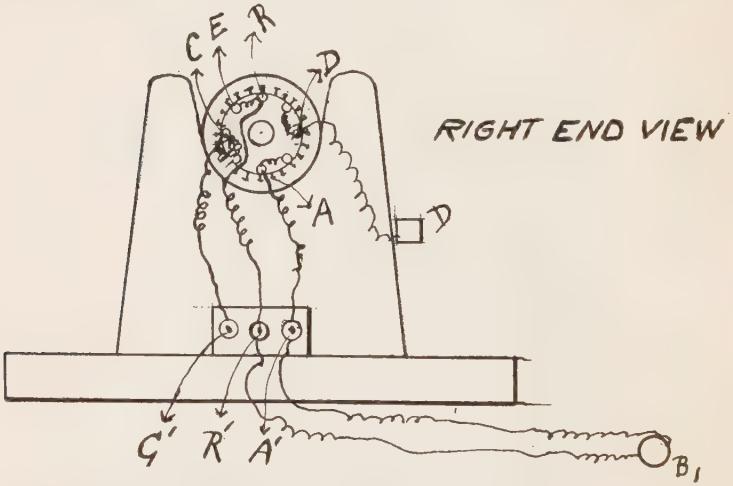
Fig. 5.



Small glass hooks fused to the edge of the disc support the wires. In fig. 6 it may be seen how one wire or arm is mounted. One end is permanently fastened to C and the wire stretched for six lengths from disc to disc and also permanently fastened to E. The loop between E and R is a continuation of the wire and is used for adjusting it equal to the one next to it. One arm, then, is included between C and R; another one between R and D, and so on. The other end of the tube is similar to this, with the exception of not having any leads, such as AA′, fig. 6, fused into the glass for heating the bridge EF. With the bridges EF and DC, fig. 3, mounted as shown in fig. 4, and the tube GH exhausted very nearly to a Crookes vacuum, radiation was the only controlling factor for the heat in EF and DC. A storage cell with a resistance in series was used to furnish the bridge current.

There was no relay at hand sensitive enough to put this apparatus into practical effect, and since a working theory was the main point aimed at, a galvanometer, as a detector, was considered sufficient. A curve, showing the relation between the current from B_1 and the time it took to move the galvanometer needle 7 divisions, was plotted. See fig. 7 for this curve, and Table II for the data. This shows a good inverse time element. With B_1 shunted off the line and a relay in the place of the galvanometer, we would have a working scheme. It was predicted that the time required to effect a certain

Fig. 6.



throw in the galvanometer could be shortened by placing a reflector over the tube GH. For this purpose the tube was exhausted so as to get rid of convection currents. A nickel-plated sheet of copper in cylindrical form was used as a reflector. The reflector was mounted on a sliding frame OP, fig. 4. For an end view see fig. 5. With the same currents from B_1 and B_2 as were used for obtaining the curve, no difference in time required to effect a certain throw could be detected as the reflector was moved along the tube. This arrangement gave no "time element" adjustment and hence the reflector was abandoned.

The bridge current used was 0·065 amperes and the heating current ranged from this to about twice the amount. The heating current was furnished by a storage battery with a variable resistance in series.

In the frame OP, figure 4, in the place of the reflector there was placed a wire heater of cylindrical form. See figure 5 for an end view. The dots on the inner circumference represent

TABLE II (FOR FIG. 7).

Readings	Heating current in one arm in milliamperes	Time in sec. for 7 div. deflection
1	62·0	13·4
2	68·0	8·6
3	70·7	8·2
4	77·0	6·1
5	86·1	4·6
6	92·4	4·0
7	100·0	3·3
8	110·0	3·0
9	121·2	2·4
10	130·0	2·1
11	145·0	1·8

FIG. 7.

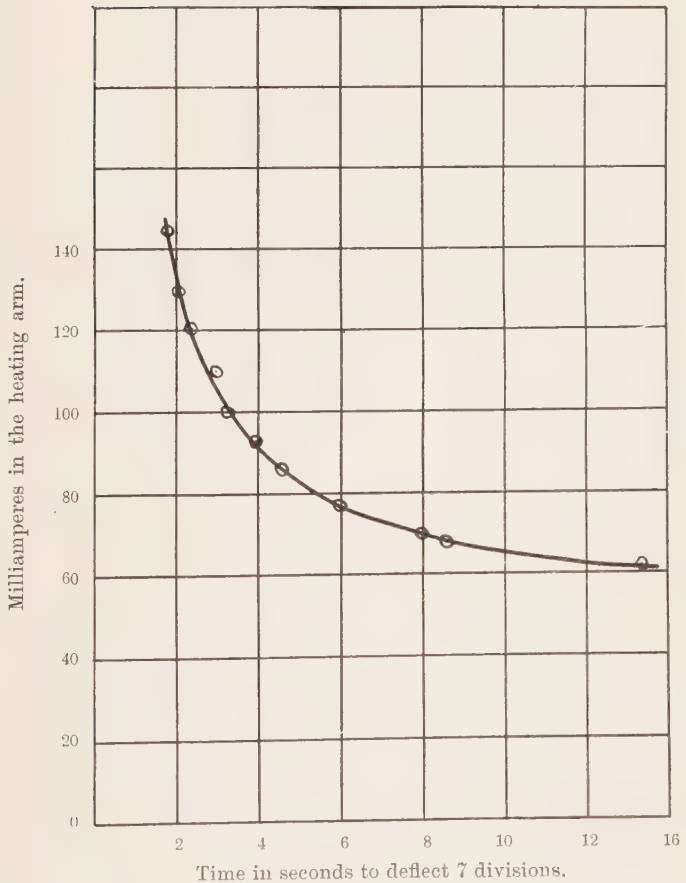


TABLE III (FOR CURVE IV, FIG. 8).

Readings	Heater setting in cm.	Time in sec. for 2 cm. defl.	Current in the heater in milliamperes
1	27·55	----	118·5
2	28·00	154·4	118·2
3	28·10	102·0	119·5
4	28·30	62·8	119·4
5	28·50	45·0	119·2
6	29·00	30·3	119·1
7	29·50	25·5	119·3
8	30·00	21·4	119·6
9	30·50	18·8	120·2
10	31·00	16·5	120·0
11	31·50	16·0	119·3
12	32·00	15·0	119·5
13	32·50	14·0	119·5
14	33·00	14 0	119·2
15	33·50	13·9	119·8

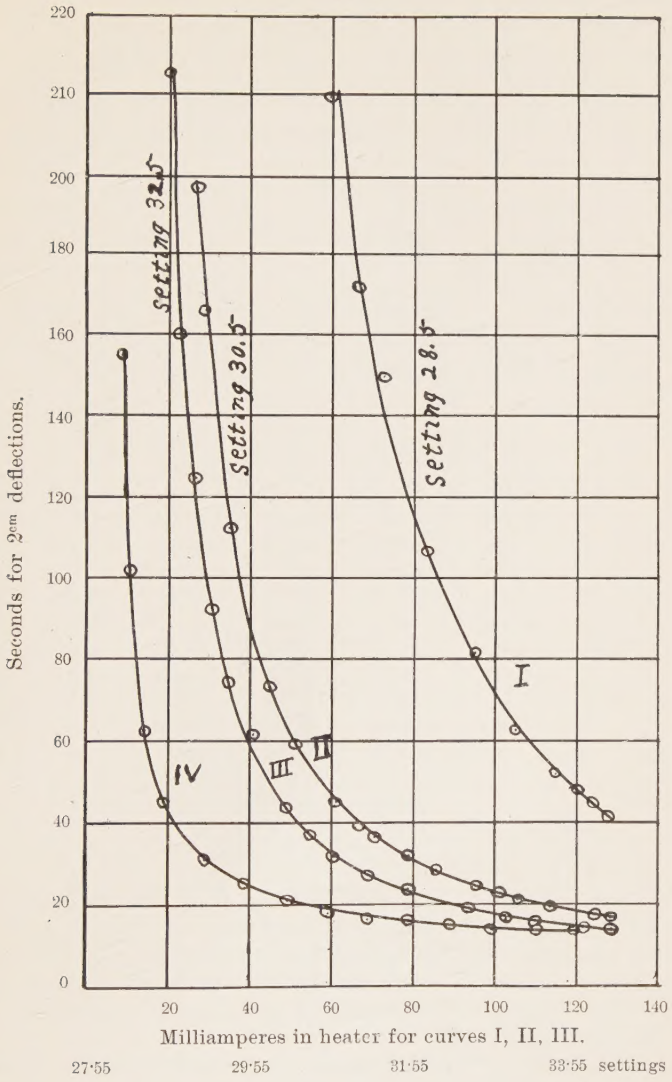
the wires, which are also shown by the full lines in figure 4. The battery B was now abandoned and the heater, joined in series with a variable resistance, connected across a 110-volt circuit. For different settings or positions of the heater over one arm of the bridge, curves were plotted connecting the current in the heater with the time for deflecting the galvanometer coil a certain number of divisions. See figure 8 for these curves and Tables III and IV for the data. For all these curves, the bridge current was very constant at 0·1 ampere. Curve IV connects the time with different settings of the heater along one arm of the bridge. The curve is parallel to the X-axis for the last three points or settings. These were positions when the heater was off one arm and only moving over the other. As seen in Table III, the heating current for this curve was nearly constant.

It was interesting to note that the electrical center for the heater, i. e., the position of symmetry, was only three millimeters away from the measured center.

It was noticed that there was a considerable time lag in the starting of the galvanometer coil after the heater switch was closed. In Table IV, for curve III, this lag is recorded.

This lag seems to indicate that the glass tube absorbed the radiation from the heater, thereby raising its temperature. This would lessen the radiation from the arm in the tube and hence raise its temperature. The change of resistance in the arm effected in this way gave rise to current in the galvanometer. This means that the current in the galvanometer is a function of the difference of temperature

FIG. 8.



between the arm and the tube. This also explains why the reflector showed no effect in time for small deflections as it was moved over the arm. The glass absorbed most of the radiation from the arm and hence the reflector had no appreciable function to perform. The apparatus was very sensitive and yet differential. Touching

the tube with the hand was sufficient to unbalance the bridge to the extent of deflecting the galvanometer as high as 20^{cms}. It was also very reliable, for it was possible to reproduce any points on the curves at any time. If the plan of having the heater on the outside of the tube is pursued, the construction is very much simplified. The space inside the tube may be

TABLE IV.

	For Curve I		For Curve II		For Curve III		
	Heater current in milli-amperes	Time in sec. for 2^{cm} defl.	Heater current in milli-amperes	Time in sec. for 2^{cm} defl.	Heater current in milli-amperes	Time in secs. for 2^{cm} defl.	Time lag.
1	60·0	220·0	27·0	196·6	20·0	226·7	6·0
2	66·9	172·4	29·1	166·6	23·0	160·5	?
3	73·1	150 0	35·8	112·4	26·5	124·8	5·8
4	83·4	107·0	45·0	73·7	31·0	92·7	5·6
5	95·4	82·0	51·0	59·5	35·0	74·8	5·0
6	105·1	63·0	61·0	45·0	41·0	61·8	5·5
7	114·8	52·4	67·0	39·2	49·2	44·1	3·9
8	120·5	48·5	70 5	36 6	55·0	37·0	3·8
9	124·5	45·0	79·0	32·0	60·5	31·6	4·0
10	127·9	41·5	85·5	28·2	69·8	27·0	3·6
11			95·3	24·8	79·0	23·5	3·2
12			101·4	23·0	94·0	19·1	3·2
13			106·0	21·3	102.6	16·8	3·4
14			113·6	19·7	110·0	15·7	3·0
15			124·5	17·8	122·0	14·4	3·2
16			128·5	17 0	128·5	13·8	3·0

made much smaller. All that is needed in the resistance is that EF and DC as a whole shall be equal.

Since the object of this paper was to study the time interval only from the experimental standpoint, there are no quantitative results given, which would be necessary for the construction of a practical relay.

I wish to thank Professor A. W. Goodspeed for the liberal allowances he made me in building the special apparatus required, and permitting me to draw freely from the resources of the laboratory.

I also acknowledge my indebtedness to Dr. R. H. Hough, who gave me many valuable suggestions, and was always ready for consultation even to the point of investigation.

Randal Morgan Laboratory of Physics,
University of Pennsylvania, May 2, 1910.